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(71) Applicant: **DOW CORNING CORPORATION**
Midland Michigan 48686-0994 (US)

(72) Inventor: **Zhong, Biznxiào**
Midland, Michigan 48640 (US)

(74) Representative:
Sternagel, Fleischer, Godemeyer & Partner
Patentanwälte
Braunsberger Feld 29
51429 Bergisch Gladbach (DE)

(54) **Method for making nanoporous silicone resins from alkylhydridosiloxane resins**

(57) A method is disclosed for preparing a nanoporous silicone resin which can be used to form low dielectric constant films useful for electrical insulating coatings on electronic devices comprising heating an alkylhydridosiloxane resin where at least 5 percent of silicon atoms are substituted with at least one alkyl group com-

prising 8 to 28 carbon atoms, at least 45 percent of the silicon atoms are bonded to hydrogen atoms, and the remaining bonds of the silicon atoms are bonded to oxygen atoms at a temperature sufficient to effect curing and thermolysis of the alkyl substituents comprising 8 to 28 carbon atoms thereby forming a nanoporous silicone resin.

Description

[0001] The present invention provides a method for making nanoporous silicone resins which are useful for forming low dielectric constant films. More specifically, the present invention provides a method for making a nanoporous silicone resin having a narrow pore size range by hydrosilating a hydrosilicon containing resin with a 1-alkene comprising 8 to 28 carbon atoms to form an alkylhydridosiloxane resin, coating the alkylhydridosiloxane resin on a substrate, and heating the coated substrate to effect thermolysis of alkyl substituents comprising 8 to 28 carbon atoms of the alkylhydridosiloxane resin to form a nanoporous silicone resin.

[0002] Semiconductor devices often have one or more arrays of patterned interconnect levels that serve to electrically couple the individual circuit elements forming an integrated circuit (IC). These interconnect levels are typically separated by an insulating or dielectric film. Previously, a silicon oxide film formed using chemical vapor deposition (CVD) or plasma enhanced techniques (PECVD) was the most commonly used material for such dielectric films. However, as the size of circuit elements and the spaces between such elements decreases, the relatively high dielectric constant of such silicon oxide films is inadequate to provide adequate electrical insulation.

[0003] In order to provide a lower dielectric constant than that of silicon oxide, dielectric films formed from siloxane-based resins have found use. An example of such films are those formed from poly(hydrogen)silsesquioxane resins as described in U.S. Patents 3,615,272 and 4,756,977. While such films provide lower dielectric constants than CVD or PECVD silicon oxide films and also provide other benefits such as enhanced gap filling and surface planarization, typically the dielectric constants of such films are limited to approximately 3 or greater.

[0004] It is well known that the dielectric constant of the above discussed insulating films is an important factor where IC's with low power consumption, cross-talk, and signal delay are required. As IC dimensions continue to shrink, this factor increases in importance. As a result, siloxane based resin materials and methods for making such materials that can provide electrically insulating films with dielectric constants below 3 are desirable. In addition it is desirable to have siloxane-based resins and method for making such resins that provide low dielectric constant films which have a high resistance to cracking. Also, it is desirable for such siloxane-based resins to provide low dielectric constant films by standard processing techniques.

[0005] It is known that the dielectric constant of solid films decrease with a decrease in density of the film material. Therefore considerable work is being conducted to develop porous insulating films for use on semiconductor devices.

[0006] U.S. Patent 5,494,859 describes a low dielectric constant insulating layer for an integrated circuit structure and a method of making the layer. A porous layer is formed by depositing on a structure a composite layer comprising an insulating matrix material and a material which can be converted to a gas upon subjection to a converting process. Release of the gas leaves behind a porous matrix of the insulating material which has a lower dielectric constant than the composite layer. The matrix forming material is typically silicon oxide and the material which can be converted to a gas upon subjection to a converting process is exemplified by carbon.

[0007] U.S. Patent 5,776,990 describes an insulating foamed polymer having a pore size less than 100 nm made from a copolymer comprising a matrix polymer and a thermally decomposable polymer by heating the copolymer above the decomposition temperature of the decomposable polymer. The copolymers described are organic polymers that do not contain silicon atoms.

[0008] WO 98/49721 describes a process for forming a nanoporous dielectric coating on a substrate. The process comprises the steps of blending an alkoxysilane with a solvent composition and optional water; depositing the mixture onto a substrate while evaporating at least a portion of the solvent; placing the substrate in a sealed chamber and evacuating the chamber to a pressure below atmospheric pressure; exposing the substrate to water vapor at a pressure below atmospheric pressure and then exposing the substrate to base vapor.

[0009] Japanese Laid-Open Patent (HEI) 10-287746 describes the preparation of porous films from siloxane-based resins having organic substituents which are oxidized at a temperature of 250°C. or higher. The useful organic substituents which can be oxidized at a temperature of 250°C. or higher given in this document include substituted and unsubstituted groups as exemplified by 3,3,3-trifluoropropyl, β phenethyl group, t-butyl group, 2-cyanoethyl group, benzyl group and vinyl group.

[0010] *J. Mat. Chem.*, 1999, 9, 591-598, reports a method to fabricate angstrom size pores in poly(methylsilsesquioxane) films in order to decrease the density and the dielectric constant of the films. Copolymers bearing methyl(trisiloxysilyl) units and alkyl(trisiloxysilyl) units are spin-coated on to a substrate and heated at 250°C. to provide rigid siloxane matrices. The films are then heated at 450°C. to 500°C. to remove thermally labile groups and holes are left corresponding to the size of the substituents. Trifluoropropyl, cyanoethyl, phenylethyl and propyl groups were investigated as the thermally labile substituents.

[0011] WO 98/47941 describes a process for preparing organohydridosiloxane resins.

[0012] WO 98/47944 describes an organohydridosiloxane polymer having a cage conformation, at least approximately 40 mole percent carbon containing substituents and a dielectric constant of less than 2.7. '944 teaches the organic substituent of the organohydridosiloxane can be a normal or branched alkyl comprising 1 to 20 carbon atoms.

In the examples, '944 demonstrates that the organic substituent can be methyl, phenyl, benzyl, tert-butyl and chloromethyl and that organohydridosiloxane polymers containing such substituents can be heated at temperatures ranging from 380°C. to 450°C. to provide cured resins having dielectric constants ranging from 2.43 to 2.66.

[0013] WO 98/47945 teaches organohydridosiloxane polymer having between approximately 0.1 to 40 mole percent carbon-containing substituents, and a dielectric constant of less than 3.0. '945 teaches that the organic substituent of the polymer can be normal and branched alkyls. In the examples, '945 demonstrates that the organic substituents can be methyl, ethyl, propyl, n-butyl, cyclohexyl, phenyl, t-butyl and trifluoropropyl. '945 demonstrates that organohydridosiloxane containing the described organic substituents can be cured by heating at temperatures ranging from 380°C. to 425°C., and that such cured materials can have a dielectric constant ranging from 2.82 to 3.09.

[0014] It is clear from the examples provided in the above referenced Hacker et al. documents that Hacker et al. did not appreciate the improvement in dielectric constants that could be achieved by hydrosilating hydridosiloxane resins with 1-alkenes comprising 8 to 28 carbon atoms to form alkylhydridosiloxane resins and subsequently curing the resin and thermolysing the alkyl substituents comprising 8 to 28 carbon atoms of the alkylhydridosiloxane resins to form nanoporous siloxane resins. Generally, the organic substituents of the organohydridosiloxane resins used in the examples of Hacker et al. were too small to provide the amount of porosity required for optimal dielectric constants for the cured resins.

Our invention provides a method for preparing a nanoporous silicone resin which can be used to form low dielectric constant films useful for electrical insulating coatings on electronic devices. The method for preparing a nanoporous silicone resin comprises heating an alkylhydridosiloxane resin where at least 5 percent of silicon atoms are substituted with at least one alkyl group comprising 8 to 28 carbon atoms, at least 45 percent of the silicon atoms are bonded to hydrogen atoms, and the remaining bonds of the silicon atoms are bonded to oxygen atoms at a temperature sufficient to effect curing and thermolysis of the alkyl substituents comprising 8 to 28 carbon atoms thereby forming a nanoporous silicone resin. Alternatively a nanoporous silicone resin coating may be prepared by first coating a substrate with the above alkylhydridosiloxane resin.

[0015] Preferably the method comprises (A) contacting a hydridosilicon containing resin with a 1-alkene comprising 8 to 28 carbon atoms in the presence of a platinum group metal-containing hydrosilation catalyst effecting formation of an alkylhydridosiloxane resin where at least 5 percent of silicon atoms are substituted with at least one alkyl group comprising 8 to 28 carbon atoms and at least 45 percent of silicon atoms are substituted with at least one hydrogen atom and (B) heating the alkylhydridosiloxane resin of step (A) at a temperature sufficient to effect thermolysis of alkyl groups comprising 8 to 28 carbon atoms of the alkylhydridosiloxane thereby forming a nanoporous silicone resin.

[0016] The hydridosilicon containing resin can be any of those known in the art where at least 50 percent of the silicon atoms have a hydrogen substitution and as such can be homopolymers or copolymers. The possible hydrolysates and co-hydrolysates are: $(\text{HSiO}_{3/2})_n$, $(\text{H}_2\text{SiO})_m$, $(\text{HSiO}_{3/2})_x(\text{R}^1\text{SiO}_{3/2})_y$, $(\text{HSiO}_{3/2})_x(\text{R}^1\text{R}^2\text{SiO})_y$, $(\text{HSiO}_{3/2})_x(\text{R}^1\text{R}^2\text{SiO})_y(\text{SiO}_2)_z$ and $(\text{HSiO}_{3/2})_x(\text{H}_2\text{SiO})_y$; where R^1 is a substituent which is not removed by heating at a temperature up to 600°C., R^2 is either R^1 or hydrogen, $n \geq 2$, $m \geq 3$, the mole fractions of x , y and z must total 1 in each of the copolymers, and x is at least 50 percent of the sum of x , y and z . Examples of R^1 include methyl, ethyl and phenyl. Hydridosilicon containing resins useful in the present process and their methods for preparation can be those described in U.S. Patents 3,615,272; No. 5,063,267 and 5,010,159. Preferred is when the hydridosilicon containing resin is selected from the group of hydridosiloxane resins described by formulas $(\text{HSiO}_{3/2})_n$, $(\text{H}_2\text{SiO})_m$ and $(\text{HSiO}_{3/2})_x(\text{H}_2\text{SiO})_y$ where n , m , x and y are as described above. More preferred is when n is an integer within a range of 100 to 1000, m is an integer within a range of 100 to 1000, and x and y are each one or greater and $x + y$ is within a range of 100 to 1000. Most preferred is when the hydridosilicon containing resin is a hydridosiloxane resin described by formula $(\text{HSiO}_{3/2})_n$ where n is as described above and n is preferably within a range of 100 to 1000.

[0017] It is preferred that the hydridosilicon containing resin be diluted in an organic solvent that is not detrimental to the hydrosilation reaction. The organic solvent can be generally any nonaromatic organic solvent that does not contain carbon-carbon unsaturated bonds and aromatic solvents. The organic solvent can be substituted or unsubstituted. Examples of useful organic solvents include alkanes such as dodecane, n-pentane, hexane, n-heptane and isooctane; cycloalkanes such as cyclopentane and cyclohexane; aromatics such as benzene, toluene, xylene and mesitylene; ketones such as methylisobutylketone; halogen substituted alkanes such as trichloroethane; and halogen substituted aromatics such as bromobenzene and chlorobenzene. Additionally, combinations of the above organic solvents may be used together as cosolvents for the hydridosilicon containing resin. The preferred organic solvents are aromatic compounds because of their high volatility, with toluene and mesitylene being most preferred because of their safety profile.

[0018] It is preferred that the hydridosilicon containing resin be diluted in the organic solvent at a weight percent within a range of 5 to 60 weight percent of the solution comprising the resin and organic solvent. More preferred is when the hydridosilicon containing resin is diluted in the organic solvent at a weight percent within a range of 10 to 30 weight percent on the same basis.

[0019] In the present method the hydridosilicon containing resin is contacted with a 1-alkene comprising 8 to 28

carbon atoms. The 1-alkene can be straight chained or branched and may be substituted or unsubstituted. Substituted 1-alkenes include those for example having hydroxy substitution, 1-alkenes having acyloxy substitution such as described by formula $\text{CH}_2=\text{CH}(\text{CH}_2)_a\text{OC}(\text{O})(\text{CH}_2)_b\text{CH}_3$, alkoxycarbonyl substitution such as described by formula $\text{CH}_2=\text{CH}(\text{CH}_2)_a\text{C}(\text{O})\text{O}(\text{CH}_3)_b\text{CH}_3$, alkoxy substitution such as described by formula $\text{CH}_2=\text{CH}(\text{CH}_2)_a\text{O}(\text{CH}_2)_b\text{CH}_3$, carbonyl substitution such as described by formula $\text{CH}_2=\text{CH}(\text{CH}_2)_a(\text{O})(\text{CH}_2)_b\text{CH}_3$, and cycloalkyl substitution such as described by formula $\text{CH}_2=\text{CH}(\text{CH}_2)_a\text{R}^3$ where R^3 is a cycloalkyl group comprising 5 to 10 carbon atoms, $a \geq 0$, $b \geq 0$, and the total number of carbon atoms in the substituted 1-alkene is within a range of 8 to 28.

[0020] It is preferred that the 1-alkene be a branched 1-alkene since the present inventors have discovered that during thermolysis the resulting branched alkyl groups substituted on the alkylhydrosiloxane resin release lower molecular weight hydrocarbon components than linear alkyl substitutions having a comparable number of carbon atoms and thus the thermolysis products are more easily removed from the cured nanoporous siloxane resins. Examples of 1-alkenes useful in the present process include 1-octene, 1-decene, 1-dodecene, 1-eicosene, 1-pentatriacontene and 3,7,11,15-tetramethyl-1-hexadecen-3-ol. It is preferred that the 1-alkene be an unsubstituted straight or branched chain molecule comprising 12 to 20 carbon atoms or 3,7,11,15-tetramethyl-1-hexadecen-3-ol (isophytol), with isophytol being most preferred. Preferred is when the 1-alkene is selected from the group consisting of 1-eicosene, 1-dodecene, and 3,7,11,15-tetramethyl-1-hexadecen-3-ol.

[0021] It is necessary in the present method that after the hydrosilation reaction at least 45 percent of the silicon atoms remain substituted with at least one hydrogen atom to retain curing ability of the silicon resin. Generally, this amount of hydrogen atoms bonded to silicon atoms in the resin can be achieved by adding an amount of 1-alkene comprising 8 to 28 carbon atoms to the present method such that the mole ratio of the 1-alkene to silicon-bonded hydrogen in the hydrosilicon containing resin is within a range of 0.05:1 to 0.7:1, with a range of 0.1:1 to 0.5:1 being preferred.

[0022] The present method requires the presence of a platinum group metal-containing hydrosilation catalyst. The platinum group metal-containing hydrosilation catalyst can be any of those known in the art to effect a hydrosilation reaction between a silicon-bonded hydrogen atom and an unsaturated carbon-carbon bond. By "platinum group metal", it is meant ruthenium, rhodium, palladium, osmium, iridium, and platinum, with platinum being preferred. Examples of platinum group metal-containing catalysts which may be useful in the present invention are described in U.S. Patents 3,419,593; 3,989,668; 5,036,117; 3,159,601; 3,220,972; 3,296,291; 3,516,946; 3,814,730 and 3,928,629. A preferred platinum group metal-containing catalyst is a complex of platinum with 1,3-diethenyl-1,1,3,3-tetramethyldisiloxane.

[0023] The amount of platinum group metal-containing catalyst useful in the present method is not narrowly limited providing there is a sufficient amount present to accelerate a reaction between silicon-bonded hydrogen atoms and the 1-alkene comprising 8 to 28 carbon atoms. The appropriate amount of the platinum group metal-containing catalyst will depend upon the particular catalyst used. In general as low as 0.001 part by weight of platinum group metal for every million parts by weight of components present in Step (A), including any solvent when present, may be useful. Preferably the amount of platinum group metal is at least 1 ppm on the same basis, with 10 to 100 ppm being more preferred, and 20 to 60 ppm being most preferred.

[0024] The temperature at which the hydrosilicon containing resin is contacted with the 1-alkene comprising 8 to 28 carbons is not critical as long as it does not effect significant gelation or curing of the alkylhydrosiloxane resin product. Generally the temperature can be within a range of 20°C. to 150°C., with a temperature within a range of 50°C. to 100°C. being preferred.

[0025] In step (A) of the present method an alkylhydrosiloxane resin is formed where at least 5 percent of the silicon atoms are substituted with at least one alkyl group comprising 8 to 28 carbon atoms and at least 45 percent of silicon atoms are substituted with at least one hydrogen atom. Preferred is where 10 to 25 percent of the silicon atoms are substituted with at least one alkyl group comprising 8 to 28 carbon atoms and at least 70 percent of the silicon atoms are substituted with at least one hydrogen atom.

[0026] In step (B) of the present method the alkylhydrosiloxane resin of step (A) is heated at a temperature sufficient to effect thermolysis of alkyl groups comprising 8 to 28 carbon atoms from the silicon atoms. The heating may be conducted as a single-step process or as a two-step process. In the two-step process the alkylhydrosiloxane resin is first heated at a temperature sufficient to effect curing without significant thermolysis of the alkyl groups comprising 8 to 28 carbon atoms from the silicon atoms. Generally, this temperature can be in a range of from 20°C. to 350°C. Then, the cured silicone resin is further heated at a temperature within a range of greater than 350°C. up to the lessor of the decomposition temperature of the silicon resin polymer backbone or R^1 substituents (as described above) on the silicon atoms to effect thermolysis of the alkyl groups comprising 8 to 28 carbon atoms from the silicon atoms. Generally, it is preferred that the thermolysis step be conducted at a temperature in a range of greater than 350°C. to 600°C., with a temperature in a range of 400°C. to 550°C. being most preferred. In the single-step heating process the curing of the silicone resin and thermolysis of the alkyl groups comprising 8 to 28 carbon atoms are effected simultaneously by heating the alkylhydrosiloxane resin to a temperature within a range of greater than 350°C. up to the lessor of the decomposition temperature of the silicone resin polymer backbone or R^1 substituents on the silicon atoms.

Preferably the single-step method of heating should be conducted at a temperature in a range of greater than 350°C. to 600°C., with a temperature in a range of 400°C. to 550°C. being most preferred.

[0027] In the present method, it is preferred that the heating of step (B) be conducted in an inert atmosphere. The inert atmosphere is useful because the presence of oxygen may oxidize Si-H bonds and cause the formation of silanol groups resulting in an increased dielectric constant (DK) for the resin. The inert atmosphere can be any of those known in the art, for example argon, helium or nitrogen.

[0028] The thermolysis of the alkyl groups comprising 8 to 28 carbon atoms results in the formation of a nanoporous silicone resin. The nanoporous silicone resins formed by the present method are particularly useful as low dielectric films on electronic devices such as integrated chips. The silicon resins of the invention can generally be applied to the surface of electronic devices in the form of a dilute solvent solution by methods such as spin coating, dip coating, spray coating or flow coating. The solvent is then allowed to evaporate by drying to form a homogeneous resin which is then heated as described above to cure and provide for a nanoporous silicone resin having a dielectric constant less than preferably 2.5. The useful solvents can be the same as those described above for use in the hydrosilation step.

[0029] The silicone resins made by the present method are nanoporous. The term "nanoporous" means a silicone resin having a median pore diameter less than 20 nm. A preferred embodiment of the present invention is an electronic substrate having a nanoporous coating of the silicone resin. In the preferred embodiment of the invention, the nanoporous silicone resin coating preferably has a median pore diameter within a range of 0.3 nm to 2 nm. Such nanoporous silicone resins may also be made in particulate form by standard methods such as spray drying and heating as described above to make nanoporous and used in such applications as packing in chromatography columns and other such applications where porous materials are used.

Example 1

[0030] This example illustrates the treatment of a hydrosilicon containing resin with a 1-alkene in the presence of a platinum catalyst. The 1-alkene was either 1-octadecene or 1-dodecene as described in Table 1. The hydrosilicon containing resin was a poly(hydrogen)silsesquioxane resin powder with a weight average molecular weight of 70,000. The weight parts of 1-alkene and toluene solvent per part of the poly(hydrogen)silsesquioxane resin and mole ratios of 1-alkene/Si atoms in the resin are listed in Table 1. The toluene solution of the resin was reacted with the 1-alkene at 110°C. in the presence of 1.2×10^{-5} weight part of platinum in the form of a complex with 1,3-diethenyl-1,1,3,3-tetramethyldisiloxane for 2 hours. The mole percents of Si-H that reacted with the 1-alkene were measured by solution FTIR using a Perkin Elmer 1600 FTIR made by the Perkin-Elmer Corporation, Norwalk, CT, and the results are listed in Table 1.

Table 1

Treatment of Poly(hydrogen)silsesquioxane Resin With 1-Alkene					
Samp 1e No.	Type of 1-alkene	Wt. parts of 1-alkene	Wt. parts of toluene	Mole ratio 1-alkene/Si	Mole % of Si-H reacted
1-1	1-ctadecene	1.60	2.22	0.33	31
1-2	1-ctadecene	1.10	2.72	0.23	21
1-3	1-ctadecene	0.85	2.97	0.18	20
1-4	1-ctadecene	0.60	3.22	0.12	14
1-5	1-ctadecene	0.35	3.47	0.07	6
1-6	1-ctadecene	0.15	3.67	0.03	3
1-7	1-dodecene	1.10	2.72	0.35	29
1-8	1-dodecene	0.85	2.97	0.27	28
1-9	1-dodecene	0.60	3.22	0.19	21
1-10	1-dodecene	0.35	3.47	0.11	12
1-11	1-dodecene	0.15	3.67	0.05	5

Example 2

[0031] This example consists of three steps. In Step 1, a poly(hydrogen)-silsesquioxane resin was treated with var-

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ious amounts of 1-octadecene under the same conditions as those for samples 1-1 to 1-6 in Example 1. Sample 2-7 is the poly(hydrogen)-silsesquioxane resin solution in toluene (4.72 parts of toluene per part of resin) not reacted with 1-octadecene. In Step 2, a 2 g sample of each resin solution prepared in Step 1 was placed into a ceramic crucible, heated at 350°C. in nitrogen for 0.5 hour, and then heated at 500°C. in nitrogen for 1 hour. The resulting solids were tested for nitrogen adsorption at - 196°C. using a Micromeritics ASAP 2000 Accelerated Surface Area and Porosimetry System. Porosity for each sample was calculated from its total pore volume obtained from the adsorption analysis using a density of 1.5 g/cc for the untreated resin solid. In Step 3, a sample of each resin solution prepared in Step 1 was diluted with toluene to 17 weight percent, and a thin film was prepared from each diluted resin solution by spin coating on a silicon wafer. The coated wafers were heated in a nitrogen atmosphere at 450°C. for 20 minutes, and their dielectric constants (DK) were measured. Table 2 lists weight ratios of 1-octadecene/(1-octadecene + resin) in each resin solution, porosity obtained in Step 2, and dielectric constants obtained in Step 3.

Table 2.

Effects of 1-Octadecene Concentration on Porosity and Dielectric Constants			
Sample No.	Weight ratio of 1-octadecene/(1-octadecene + resin)	Porosity %	DK
2-1	61.5	27.1	2.1
2-2	52.4	27.9	2.2
2-3	46.0	24.3	2.2
2-4	37.5	23.6	2.1
2-5	25.9	18.8	2.5
2-6	13.0	0.2	2.7
2-7	0	0	3.0

Example 3

[0032] Samples 3-1 to 3-9 were prepared and tested according to the procedures described in Example 2, except that the weight parts of all 1-alkenes (linear alpha alkenes described by general formula C_nH_{2n}) were fixed at 0.84 weight part per weight part of the resin, and those of toluene were 3 weight parts per weight part of the resin. The values for subscript y are provided in Table 3. Median pore diameters for cured solids from samples 3-1 to 3-6 were calculated by H-K analysis (Horvath, J. Chem. Eng. Jpn., 1983, Vol. 16, page 476) of the nitrogen adsorption data. Sample 3-1 resulted in a cracked film, so no dielectric constant was measured for it.

Table 3.

Porosity and dielectric constant data for cured resins treated with different alkenes.						
Sample #	1-Alkene y =	BET surface area, m ² /g	Porosity %	Median pore diameter, nm	Crack-free film	DK
3-1	30	892	37.8	0.78	N	NA
3-2	20	620	30.5	0.62	Y	2.0
3-3	18	570	28.5	0.63	Y	2.1
3-4	16	603	29.7	0.62	Y	2.0
3-5	14	546	27.6	0.62	Y	2.1
3-6	12	536	27.2	0.61	Y	2.1
3-7	10	453	23.1	NA	Y	2.2
3-8	8	422	21.9	NA	Y	2.3
3-9	7	391	20.4	NA	Y	2.6

Example 4

[0033] Samples 4-1, 4-2 and 4-3 were prepared and tested according to procedures described in Example 3, except that the 1-alkenes were branched and/or substituted. The results are reported in Table 4.

Table 4.

Porosity and Dielectric Data For Resins Treated With Substituted 1-Alkenes.						
Sample No.	1-Alkene type	BET surface area, m ² /g	Porosity %	Median pore diameter nm	Crack-free film	DK
4-1	isophytol (3,7,11,15-tetramethyl 1-hexadecen-3-ol)	751	33.1	0.65	Y	1.9
4-2	allyl heptanoate	478	25.0	0.57	Y	2.5
4-3	allyl cyclohexane- propionate	451	24.0	0.56	Y	2.3

Sample 5

[0034] Sample 5-1 was prepared under the same conditions as those for sample 3-2 in Step 1 of Example 3, sample 5-2 was prepared under the same conditions as those for sample 3-6 in Step 1 of Example 3, and sample 5-3 was prepared under the same conditions as those for sample 4-1 in Step 1 of Example 4. A sample of 5 g of each of the toluene solution of the resins was then heated in a crucible at 300°C. for 1 hour in nitrogen to yield a solid resin. Then, each solid resin was heated in a quartz tube at 450°C. for 1 hour under a nitrogen flow and the released volatiles removed in the nitrogen were collected with a cold trap at -196°C. The collected volatiles were analyzed by GC. Volatiles from sample 5-1 consisted mainly of hydrocarbons with 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7 and 6 carbon atoms, those from sample 5-2 consisted mainly of hydrocarbons with 11, 10, 9, 8, 7 and 6 carbon atoms, and those from sample 5-3 mainly consisted of hydrocarbons with 9, 8, 7 and 6 carbon atoms.

Claims

1. A method for preparing a nanoporous silicone resin comprising heating an alkylhydrosiloxane resin where at least 5 percent of silicon atoms are substituted with at least one alkyl group comprising 8 to 28 carbon atoms, at least 45 percent of the silicon atoms are bonded to hydrogen atoms, and the remaining bonds of the silicon atoms are bonded to oxygen atoms at a temperature sufficient to effect curing and thermolysis of the alkyl substituents comprising 8 to 28 carbon atoms thereby forming a nanoporous silicone resin.
2. A method for preparing a nanoporous silicon resin coating on a substrate comprising the steps of (A) coating on to a substrate an alkylhydrosiloxane resin where at least 5 percent of silicon atoms are substituted with at least one alkyl group comprising 8 to 28 carbon atoms, at least 45 percent of the silicon atoms are bonded to hydrogen atoms, and the remaining bonds of the silicon atoms are bonded to oxygen atoms, and (B) heating the coated substrate to a temperature sufficient to effect curing of the alkylhydrosiloxane resin coating and thermolysis of alkyl groups comprising 8 to 28 carbon atoms thereby forming a nanoporous silicon resin coating on the substrate.
3. The method of any of the preceding claims wherein the alkylhydrosiloxane resin is prepared by contacting a hydrosiloxane resins with a 1-alkene comprising 8 to 28 carbon atoms in the presence of a platinum group metal-containing hydrosilation catalyst.
4. The method of claim 3 wherein the alkylhydrosiloxane is selected from resins described by formulas $(\text{HSiO}_{3/2})_n$, $(\text{H}_2\text{SiO})_m$, and $(\text{HSiO}_{3/2})_x(\text{H}_2\text{SiO})_y$, where n is within a range of 100 to 1000, m is within a range of 100 to 1000, x and y are each an integer of one or greater and x + y is within a range of 100 to 1000.
5. The method according to any of the preceding claims where the 1-alkene is a branched 1-alkene comprising 8 to 28 carbon atoms.
6. The method according to any of the preceding claims where 10 to 25 percent of the silicon atoms of the alkylhydrosiloxane resin are substituted with at least one alkyl group comprising 8 to 28 carbon atoms and at least 70 percent of the silicon atoms are substituted with at least one hydrogen atom.
7. The method according to claims 2-6 wherein the substrate is an electronic component.

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8. A nanoporous silicon resin prepared by the method of claims 1 and 3-6.
9. A substrate having a nanoporous silicone resin coating prepared by the method of claims 2-7.

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(72) Inventor: **Zhong, Bizn Xiao**
Midland, Michigan 48640 (US)

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(74) Representative:
**Sternagel, Fleischer, Godemeyer & Partner
Patentanwälte
Braunsberger Feld 29
51429 Bergisch Gladbach (DE)**

(71) Applicant: **DOW CORNING CORPORATION**
Midland Michigan 48686-0994 (US)

(54) **Method for making nanoporous silicone resins from alkylhydridosiloxane resins**

(57) A method is disclosed for preparing a nanoporous silicone resin which can be used to form low dielectric constant films useful for electrical insulating coatings on electronic devices comprising heating an alkylhydridosiloxane resin where at least 5 percent of silicon atoms are substituted with at least one alkyl group comprising 8 to 28 carbon atoms, at least 45 percent of the

silicon atoms are bonded to hydrogen atoms, and the remaining bonds of the silicon atoms are bonded to oxygen atoms at a temperature sufficient to effect curing and thermolysis of the alkyl substituents comprising 8 to 28 carbon atoms thereby forming a nanoporous silicone resin.



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EUROPEAN SEARCH REPORT

Application Number

EP 00 12 5883

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			C09D H01L C08G
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 18 February 2002	Examiner Depijper, R
CATEGORY OF CITED DOCUMENTS X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons &: member of the same patent family, corresponding document			

**ANNEX TO THE EUROPEAN SEARCH REPORT
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